



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 :

H01Q 1/28, 1/08, B64G 1/44, 1/58

A1

(11) International Publication Number:

WO 94/29927

(43) International Publication Date: 22 December 1994 (22.12.94)

(21) International Application Number:

PCT/US94/06261

(22) International Filing Date:

8 June 1994 (08.06.94)

(30) Priority Data:

08/075,425

11 June 1993 (11.06.93)

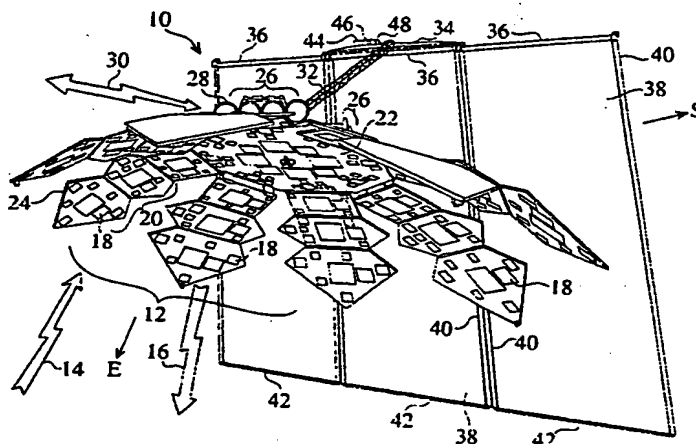
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360 Forest Avenue, Suite 201, Palo Alto, CA 94301 (US).(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CN,
CZ, DE, DK, ES, FI, GB, HU, JP, KP, KR, KZ, LK, LU,
LV, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD,
SE, SK, UA, UZ, VN, European patent (AT, BE, CH, DE,
DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI
patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE,
SN, TD, TG).

Published

*With international search report.**Before the expiration of the time limit for amending the
claims and to be republished in the event of the receipt of
amendments.*

(54) Title: MODULAR COMMUNICATION SATELLITE



(57) Abstract

The preferred embodiment of the *Modular Communication Satellite* (10) includes a foldable, high-gain, electronically steered antenna array (12) that is always pointed toward the Earth (E). The unfolded spacecraft resembles an opened flower. Polygonal antenna panels (92, 94, 96, 102, 104, and 106) are attached to each other and to a primary bus structure (22) by antenna deployment hinges (90). The upper portion of the satellite (10) incorporates intersatellite antenna arrays (26) of individual intersatellite antennas (28), which are always pointed tangentially to the Earth (E). An Astromast™ boom (32) is mounted between the space facing surface of the primary bus structure (22) and an assembly of solar array storage booms (36). The Astromast™ boom (32) can expand and rotate amorphous silicon solar arrays (38) which are unfurled from within the solar array storage booms (36). The amorphous silicon solar arrays (38) gather solar radiation to provide power the satellite (10), and furnish thermal control for the satellite (10) by shielding it from solar radiation. The satellite is capable of being nested or stacked in a compact arrangement that fits within a payload bay of a launch vehicle (LV).

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MODULAR COMMUNICATION SATELLITE

TECHNICAL FIELD

The present invention relates to the field of satellites. More particularly, this invention is an integral part of a communications network comprising a constellation of 840 extremely high power and ultra-lightweight spacecraft which circle the globe in low Earth orbit. The satellites operate in 700 km (435 mile) circular, Sun-synchronous orbits which are inclined approximately 98.2 degrees to the Equator.

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BACKGROUND ART

Communications satellites operating in Earth orbit were first seriously proposed during the middle of this century. A relatively small portion of current telephone traffic is relayed between ground stations by spacecraft carrying transponders that are located over a fixed portion on the Earth in 22,300 mile geosynchronous orbits. Over the past few decades, public phone systems have relied primarily on land lines and microwave repeaters to handle call traffic. Cellular networks now provide service which extends previous network capabilities. Customers using hand-held portable phones or carphones are now able to access the conventional, centralized land-based system without using a traditional fixed phone, as long as their transportable terminals are within the range of land-based antenna towers called "cell sites." Even in the United States, these cell sites are not universally prevalent, since market forces restrict cellular service to only the most densely populated urban portions of our country. Since cellular service is available to only a small minority of privileged users in wealthy countries, and is virtually non-existent in lesser developed parts of the world, the operators of traditional phone networks are confronted with serious systemic problems that severely constrain the continued growth of their communications utilities.

In the past decade, several satellite systems have been proposed as a means of expanding and extending conventional land-based telephone networks. The implementation of these proposed satellite systems requires new spacecraft designs which would permit a great number of satellites to be launched efficiently and economically.

A spacecraft design that pertains to the compact nesting of multiple spacecraft in the same launch vehicle has partially been addressed by Mark G. Rochefort. In International Application Number PCT/US88/02365, Rochefort considered using a substantially cup-shaped configuration for stored spacecraft to allow a large number of identically shaped spacecraft to be stored together in the stowage compartment of a launch vehicle. This approach did not anticipate the large number of antennas necessary for a satellite in a large communications system. Rochefort did not consider the advantage of storing solar arrays near the antenna arrays. He also did not consider unfurling a solar array away from the antenna arrays. Rochefort's stowage of satellites in a cup-shaped manner also unnecessarily exposes the surfaces of a satellite to damage during storage, launch and placement into orbit.

No system that is currently available to the general public is capable of taking advantage of the enormous augmentation of communications capacity that could be achieved if the traditional centralized grid of terrestrial switches, wires, fibers, and microwave repeaters could be completely bypassed. Public phone companies are not presently able to sell continuous global service to their customers who wish to use phones that are not hard-wired to the land-based network. Some commercial spacecraft now in service help to relay some portion of the total call traffic, but all these calls must still pass through the conventional land-based system. The problem of providing an economically feasible network for voice, data, and video which can be used by subscribers all over the world has presented a major challenge to the communications business.

The development of a constellation of reliable, high gain satellites which can communicate directly to terrestrial terminals without routing calls through land-based networks would constitute a major technological advance and would satisfy a long felt need within the electronics and telephone industries.

An appreciation of other aims and objectives of the present invention and a more complete and comprehensive understanding of this invention may be achieved by studying the following description of a preferred embodiment and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of the present invention, as it would appear in its fully opened and deployed position in low Earth orbit. This illustration shows how the present invention would be deployed to provide communications links to Earth and to other satellites in its constellation.

Figure 2 is a perspective view of the assembled satellite, before being launched and deployed into low Earth orbit.

Figure 3 is a front view of the assembled satellite, which shows a lower region in which the folded antenna arrays are located, and an upper region where intersatellite antennas, extension and storage booms, and solar arrays are located.

Figure 4 offers a detailed side view of the assembled satellite in its predeployed state. From this view, details of one of the three solar array storage booms can be seen.

Figure 5 is a front view of an assembled satellite before being placed into a launch vehicle.

Figure 6 is a top view of a satellite within a launch vehicle.

Figure 7 is a bottom view of a satellite within a launch vehicle.

Figure 8 is a side cut-away view of a launch vehicle with a payload of satellites.

Figure 9 is an illustration of a satellite deployed in low Earth orbit.

Figure 10 is an illustration of a deployed satellite that depicts how the solar array storage booms would first detach from the rest of the satellite.

Figure 11 shows an illustration of a deployed satellite with an extending Astromast™ boom.

Figure 12 depicts the expansion of the solar array storage booms and the extension of the outer antenna arrays during deployment of the satellite in low Earth orbit.

Figure 13 shows the fully extended solar array storage booms and extension of the inner antenna arrays.

5 Figure 14 illustrates the inflation and expansion of solar arrays from the solar array storage booms.

Figure 15 provides a perspective view of the fully deployed solar arrays on the satellite.

Figure 16 is a side view of a fully extended and deployed satellite.

Figure 17 is a front view of a fully deployed satellite.

10 Figure 18 is an illustration of the fully deployed Earth-facing antenna array used in the present invention.

Figure 19 is an alternate embodiment of the Earth-facing antenna arrays.

Figure 20 provides another alternate embodiment for the Earth-facing antenna arrays.

BEST MODE FOR CARRYING OUT THE INVENTION

Summary of the Invention

15 A *Modular Communication Satellite for a Satellite Communication System* is disclosed. The preferred embodiment of the invention includes a foldable, high-gain, electronically steered antenna array which is always pointed toward the Earth, and which resembles an opened flower. These Earth-facing antennas communicate with subscribers using portable, mobile and fixed terminals P, M, F and gateways G. A group of polygonal antenna panels are attached to each other and to a primary bus structure by antenna deployment hinges. The
20 upper portion of the satellite incorporates an array of individual intersatellite antennas, which are always pointed in a direction which is tangent to the Earth's surface and towards the intersatellite antenna arrays of other satellites within the satellite constellation. An Astromast™ boom is mounted between the space-facing surface of the primary bus structure and an assembly of solar array storage booms. The Astromast™ boom can expand and rotate amorphous silicon solar arrays which are unfurled from within the solar array storage booms. The
25 amorphous silicon solar arrays gather solar radiation to provide power for the satellite, and also provide thermal control for the satellite by shielding the satellite from solar radiation. The satellite is capable of being nested or stacked in a compact arrangement that fits within a payload bay of a launch vehicle.

Preferred & Alternative Embodiments

30 Figure 1 is an illustration of the satellite 10 shown as it would appear in its fully opened and deployed position in low Earth orbit. An Earth-facing antenna array 12 is used to provide reception of 30 GHz uplinks 14 and also to provide transmission of 20 GHz downlinks 16. The Earth-facing antenna array 12 comprises individual electronically steered phased-array antennas 18 located on eight mobile, fixed terminal satellite link M/FTSL antenna panel sets 20 and on the Earth-facing surface of the primary bus structure 22. Each M/FTSL

antenna panel set 20 has three adjoining antenna facet panels 24. The M/FTSL panels are deployed at angles with respect to the Earth's surface that limit the required steering angle from the satellite to the portion of the Earth surface served by this antenna. Four intersatellite link ISL antenna arrays 26 are located on the space-facing surface of the primary bus structure 22. Four individual ISL antennas 28 make up each of the ISL antenna arrays 26. The ISL antennas 28 are able to receive and to transmit 60 GHz intersatellite links 30. The 60 GHz intersatellite links 30 provide communication among the constellation of satellites.

An expandable Astromast™ boom 32 such as that produced by Astro-Spar of Carpinteria, California, is rotatably and hingedly coupled to the primary bus structure 22, and at full extension can reach approximately 12 meters in length. A boom crossmast 34 is rotatably coupled to the far end of the Astromast™ boom 32. A solar array storage boom 36 is attached to the boom crossmast 34. Two more solar array storage booms 36 are coupled to opposite ends of the first solar array storage boom 36. An amorphous silicon solar array 38 extends from each of the solar array storage booms 36. Inflatable booms 40 extend from each end of the solar array storage booms 36, and are attached to the amorphous silicon solar arrays 38. A cantilever boom 42 is attached to the far end of each of the amorphous silicon solar arrays 38, between each pair of inflatable booms 40. Structural support for each of the thin, generally rectangular, amorphous silicon solar arrays 38 is provided by the framework created by each solar array storage boom 36, a pair of inflatable booms 40, and a cantilever boom 42.

Pulse plasma thrusters 44, storage batteries 46, and shunt regulators 48 are attached to the boom crossmast 34. Propulsion for the satellite 10 is provided by six pulse plasma thrusters 44, which in this embodiment are produced by Olin RRC. The pulse plasma thrusters 44 provide propulsion to accomplish maneuvers such as orbit insertion, drag make-up, station keeping, and de-orbit that is required at the end of the lifetime of a satellite 10. Each of the pulse plasma thrusters 44 is designed to provide 60 kN*sec of thrust. This configuration affords the advantages of redundant propulsion, and also insures reliable service for the lifetime of the satellite 10.

Figure 2 is a perspective view 50 of the assembled satellite 10, before it is launched and deployed into low Earth orbit. Many of the components of the satellite 10 are designed to be stored, folded, or manipulated to achieve as small a volume as possible. This design provides an extremely compact structure that can be delivered into space economically. Four M/FTSL antenna panel sets 20 located at opposing corners of the primary bus structure 22 are folded inward to become the inner antenna arrays 52. The remaining four M/FTSL antenna panel sets 20 that are also attached to the primary bus structure 22 are also folded inward to become the outer antenna arrays 54.

Two component storage compartments 56 are located on the upper surface of the primary bus structure 22. Two ISL antenna arrays 26 are attached to the exterior of the component storage compartments 56. The amorphous silicon solar arrays 38 and inflatable booms 40 are stored inside their respective solar array storage booms 36, which are folded together and are mounted to the primary bus structure 22 by two modular aluminum solar array attachment structures 58. Two additional ISL antenna arrays 26 are attached to the solar array attachment structures 58. The component storage compartments 56 are used to house much of the required

internal systems, such as the command and data handling subsystem 60, the attitude/orbit determination and control subsystem 62, and the communications payload subsystem 64.

Figure 3 provides a front view 66 of the assembled satellite 10, which shows how the M/FTSL antenna panel sets 20 are folded underneath the primary bus structure 22. Figure 3 also illustrates how the amorphous silicon solar arrays 38 are stored effectively within the solar array storage booms 36. The scale of the assembled satellite 10 is suggested by a person PN standing approximately two meters tall alongside the satellite 10.

Figure 4 offers a detailed side view 68 of the assembled satellite 10. From this view, details of one of the three solar array storage booms 36 can be seen. Cantilever booms 42 extend between both ends of the solar array storage booms 36. Before deployment, the amorphous silicon solar arrays 38 and the inflatable booms 40 are stored within the solar array storage booms 36.

Figure 5 is a front view 70 of an assembled satellite 10 before being placed into a launch vehicle LV. After a final inspection, the satellite 10 is placed in the payload dynamic envelope PDE within the interior LVI of the launch vehicle LV, as seen in the cut-away top view 74 illustrated in Figure 6. Figure 7 provides a bottom cut-away view 78 of a satellite 10 stored within the payload dynamic envelope PDE in the launch vehicle LV. This view shows how the geometric design for the antenna facet panels 24 is chosen to supply a large amount of surface area for placement of antennas 18, while simultaneously providing an extremely compact folded structure.

Figure 8 provides a side cut-away view 80 of a launch vehicle LV with a payload of satellites 10. A number of satellites 10 are located within the payload dynamic envelope PDE area of the interior LVI of the launch vehicle LV. The advanced design techniques employed by the present invention allow a large quantity of satellites 10 to be placed within the payload dynamic envelope PDE, which insures that each satellite 10 is deployed at minimum cost. To provide a sense of scale, a person PN approximately two meters tall is shown standing near the launch vehicle LV before it is launched.

Figure 9 is an illustration 82 of a satellite 10 being deployed into a low Earth orbit, after it has been launched from the launch vehicle LV. The launch vehicle LV is capable of deploying satellites 10 either one at a time or in multiple groups. The attitude/orbit determination and control subsystem 62 located within the satellite 10 determines its current location, and compares it with the intended orbit location above the Earth E. The attitude/orbit determination and control subsystem 62 then provides the control logic necessary to activate the pulse plasma thrusters 44 to guide the spacecraft 10 into its correct orbit location.

As the guided satellite 10 approaches correct orbit location above the Earth E, the attitude/orbit determination and control subsystem 62 provides the logic necessary to begin deployment of the Astromast™ boom 32 and the solar array storage booms 36. Figure 10 is an illustration 84 that shows how the solar array storage booms 36 are disconnected from the solar array attachment structures 58, using spring-loaded, pyrotechnic, or other suitable means to promote detachment. Upon detachment, the Astromast™ boom 32 rotates axially about its couplings with the primary bus structure 22 and/or the boom crossmast 34, while

simultaneously expanding lengthwise to move the solar array storage booms 36 away from the primary bus structure 22.

Figure 11 provides a view 86 of a deployed satellite 10 in which the Astromast™ boom 32 has expanded to distance the solar array storage booms 36 from the primary bus structure 22. The attitude/orbit determination and control subsystem 62 provides the adjustment for pitch and roll reaction to the inertial moment created by the distance of the solar array storage booms 36 from the primary bus structure 22.

The Astromast™ boom 32 continues to extend to its full length. The satellite antennas and electronics operate most efficiently at low temperatures. They can most effectively dissipate the heat generated in their operation by radiating this heat via the back side of the M/FTSL antenna panel sets 20 into "cold space" which has an ambient temperature of approximately 4 degrees Kelvin. If the radiation of the Sun is allowed to impinge directly on the back surface of the M/FTSL antenna panel sets, this increases the effective ambient temperature, which would result in less efficient thermal dissipation, a higher operating temperature, and less efficiency. The present design uses the amorphous silicon solar arrays 38 as a Sun shade to effectively shield the satellite 10 from the Sun and thus to reduce the effective ambient temperature of the space into which the satellite 10 dissipates heat. This is done by using amorphous silicon solar arrays 38 that when fully extended on the Astromast™ boom 32 between the satellite 10 and the Sun and oriented perpendicular to the Sun, casts a shadow that completely covers the satellite 10, including all antenna facet panels 24. The amorphous silicon solar array position that provides maximum shading also provides the most efficient solar energy generation, since the array surface is maintained perpendicular to the Sun's rays. The extension of the Astromast™ boom 32 provides sufficient distance between the primary bus structure 22 and the amorphous silicon solar arrays 38, which, in turn, furnishes the required radiation shielding for the antennas 18 and the ISL antennas 28. In this embodiment, the Astromast™ boom 32 is approximately twelve meters long when fully extended.

Figure 12 is a illustration 88 which depicts the extension of the outer antenna arrays 54. The outer antenna arrays 54 are made up of four outer antenna arrays 54a, 54b, 54c, and 54d. They are located at four opposing corners of the primary bus structure 22. The outer antenna arrays 54 are each made up of an inner antenna panel 92, a central antenna panel 94, and an outer antenna panel 96. Each outer antenna panel 96 coupled in series to a pair of antenna deployment hinges 90, a central antenna panel 94, another pair of antenna deployment hinges 90, an inner antenna panel 92, another pair of antenna deployment hinges 90, and to the primary bus structure 22. When the outer antennas 54 are expanded, the outer antenna panels 96, the central antenna panels 94, and the inner antenna panels 92 are all unfolded, using the antenna deployment hinges 90.

Figure 12 also illustrates the expansion of the solar array storage booms 36 as the Astromast™ boom 32 reaches its fully extended length. The solar array storage booms 36 are coupled to each other using boom hinge mechanisms 98. The solar array storage booms 36 use the boom hinge mechanisms 98 to pivot away from their parallel stored position towards a coaxial arrangement.

Figure 13 is an illustration 100 which shows full extension of the solar array storage booms 36 and the outer antenna arrays 54. The solar array storage booms 36 come into coaxial alignment with each other as the boom hinge mechanisms 98 that couple them pivot to their extended positions. Each end of each solar array

storage boom 36 is coupled to a deployment mechanism 108. In Figure 13 the cantilever booms 42 can be seen as they would be attached to the solar array storage booms 36 in a parallel fashion between the deployment mechanisms 108. The boom crossmast 34 rotates to position the solar array storage booms 38 correctly for expansion of the amorphous silicon solar arrays 36. The pulse plasma thrusters 44, the storage batteries 46, and the shunt regulators 48 are seen as they are located on the boom crossmast 34.

As the outer antenna arrays 54a, 54b, 54c, and 54d continue to unfold away from the primary bus structure 22, they begin to resemble the petals of an oblate flower. The outer antenna array sets 54 are locked in place when the antenna deployment hinges 90 reach the end of their designed travel.

Figure 13 also illustrates how the inner antenna arrays 52 begin to unfold as the outer antenna arrays 54 expand away from the primary bus structure 22. The inner antenna arrays 52 are made up of four inner antenna arrays 52a, 52b, 52c, and 52d located at four opposing corners of the primary bus structure 22, in between each of the outer antenna arrays 54. The inner antenna arrays 52 are each made up of an inside antenna panel 102, a middle antenna panel 104, and an outside antenna panel 106. Each outside antenna panel 106 is coupled in series to a pair of antenna deployment hinges 90, a middle antenna panel 104, another pair of antenna deployment hinges 90, an inside antenna panel 102, another pair of antenna deployment hinges 90, and to the primary bus structure 22. The inside antenna panels 102 are attached to the primary bus structure 22 at a different offset distance than the inner antenna panels 92 of the outer antenna arrays 54. This staggered offset allows the inner antenna arrays 52 and the outer antenna arrays 54 to be advantageously stored in a minimum volume.

The expansion of the inner antenna arrays 52 is similar to the expansion of the outer antenna arrays 54, and entails the unfolding of the outside antenna panels 106, the middle antenna panels 104, and the inside antenna panels 102 using the antenna deployment hinges 90. The large surface area provided by the inner antenna arrays 52 and the outer antenna arrays 54 provides adequate room for the numerous antennas 18 that make up the Earth-facing antenna array 12, which is designed for large communications traffic within the *Satellite Communication System*.

Figure 14 is an illustration 110 of the inflation and expansion of the amorphous silicon solar arrays 38 from the solar array storage booms 36. The specialized structure of the amorphous silicon solar arrays 38 and the inflatable booms 40 enable the large, extremely light weight, amorphous silicon solar arrays 38 to be deployed from the satellite 10 economically and reliably.

The amorphous silicon solar arrays 38 comprise of photovoltaic cells 112 located on a thin film substrate 114. New polymer films, such as Mylar™ or Kapton™ are used for the film substrate 114, which is attached to the photovoltaic cells 112. Mylar™ and Kapton™ satisfy all the material requirements of the film substrate 114, and offer a useful lifetime of many years in outer space.

The inflatable booms 40 attached to the amorphous silicon solar arrays 38 are expanded by gas pressure provided by inflation gas 118 from within the deployment mechanisms 108. The inflatable booms 40 expand away from the deployment mechanisms 108, and are used to unfurl the amorphous silicon solar arrays 38 from their stored positions within the solar array storage booms 36. In one embodiment, the inflatable booms 40

have pleated, "accordion bellows" style structures. In another embodiment, the inflatable booms 40 roll out to unfurl the amorphous silicon solar arrays 38, in a similar fashion to a child's party favor. The inflatable booms 40 provide an extremely effective, light weight means for supporting the light and flexible amorphous silicon solar arrays 38.

5 Once the inflatable booms 40 are fully inflated to unfurl the amorphous silicon solar arrays 38, they are then rigidized to retain their inflated structure. A small amount of photocurable chemical vapor 116 is deposited into the inflatable booms 40 from within the deployment mechanism 108. The photocurable chemical vapor 116 mixes with the inflation gas 118, and cures on the inner surface of the inflatable booms 40 when it is exposed to ultraviolet radiation provided by the Sun S. As the photocurable chemical vapor 116 cures, it
10 forms a rigid surface on the inner walls of the inflatable booms 40. The rigid inflatable booms 40 then act together with the solar array storage booms 36 and the cantilever booms 42 to provide a long lasting ultralightweight framework for the amorphous silicon solar arrays 38. As an alternative, the booms 40 may already be coated with a photo-curable substance which is not exposed to light until the satellite is deployed in orbit. The coating could also be rendered photocurable upon the introduction of a suitable gas, or the gas could
15 be self-curing without the aid of sunlight. The inflation gas itself could also incorporate a curable or photocurable component.

Other embodiments of the present invention employ different techniques to provide an efficient framework for the amorphous silicon solar arrays 38. In one embodiment, continuous gas pressure is provided to provide sufficient rigidity for the inflatable booms 40. In another embodiment, the amorphous silicon solar
20 arrays 38 and inflatable booms 40 are combined to form an inflatable pillow-like structure that can be rigidized with photocurable chemical vapor 116.

Figure 15 provides a perspective view 120 of the fully deployed amorphous silicon solar arrays 38 on the satellite 10. The amorphous silicon solar arrays 38 provide power for the spacecraft 10 through the photovoltaic cells 112. The photovoltaic energy is produced directly from incoming solar energy when photons
25 are absorbed in the semiconductor substrate photovoltaic cells 112. Amorphous silicon is used in the preferred embodiment, since its irregular, non-crystalline arrangement allows highly efficient light absorption in an ultra-thin film. This amorphous silicon film is very lightweight, and is flexible, reliable, and extremely resistant to physical abuse. Excess power provided by the photovoltaic cells 112 is stored in the storage batteries 46. The amorphous silicon solar arrays 38 also function as a solar heat shield for the satellite 10, and provide an
30 extremely lightweight and effective active thermal control device.

Many components in an orbiting satellite function properly only if they are maintained within a rather narrow temperature range. The temperatures of satellite components are influenced by the net thermal energy exchange between the satellite and its thermal environment, which is influenced by the magnitude and distribution of radiation input from the Sun S and the Earth E.

35 The objective of satellite thermal control design is to provide the proper heat transfer between all satellite elements so that temperature sensitive components remain within their specified temperature limits. Techniques used for satellite thermal control can be passive or active. Passive techniques include thermal

coatings, thermal insulation and heat sinks. Active thermal control techniques include heat pipes, louvers, heat shields and electrical heaters.

A satellite heat pipe is a thermal device that can provide a significant transfer of thermal energy between two regions on the satellite. A heat pipe comprises a closed cylinder whose inner surfaces are lined with a wick that provides a capillary effect. Heat in the warm portion of the pipe vaporizes a working fluid. The resulting pressure difference drive the vapor to the cooler end of the tube, where the vapor condenses and releases its latent heat of vaporization. The loss of liquid in the warmer area creates a capillary pressure that promotes movement of liquid from the cooler region to the warmer region, thus creating the continuous cycle required for heat transfer. In addition to the thermal control provided by shielding by the amorphous silicon solar arrays 38, the active and passive thermal control techniques discussed may be implemented in alternative satellite embodiments to provide thermal control for the satellite 10.

Figure 16 is a side view 122 of a fully extended and deployed satellite 10. This depiction shows how the advanced design of the satellite 10 provides a large Earth-facing antenna array 12 to provide a large volume of 30 GHz uplinks 14 and 20 GHz downlinks 16, and ISL antenna arrays 26 to provide a large volume of 60 GHz intersatellite links 30. This view also illustrates how the expandable Astromast™ boom 32 is extended to position the amorphous silicon solar arrays 38 correctly.

Figure 17 is a front view 124 of a fully deployed satellite 10. This view portrays the large amorphous silicon solar arrays 38 and shows how they provide thermal heat shielding for the satellite 10. The amorphous silicon solar arrays 38 supply a large surface area of photovoltaic cells 112 which collect solar radiation and provide power for the satellite 10.

Figure 18 is an illustration 126 of the fully deployed Earth-facing antenna array 12 used in the present invention. The antennas 18 located on the inner antenna arrays 52, the outer antenna arrays 54, and the primary bus structure 22 consist of uplink antennas 18a and downlink antennas 18b. The uplink antennas 18a are used to receive 30 GHz uplinks 14, and the downlink antennas 18b are used to transmit 20 GHz downlinks 16.

Figure 19 is an alternate embodiment 128 of the Earth-facing antenna array 12. This embodiment features a different arrangement of uplink antennas 18a and downlink antennas 18b that are located on the inner antenna arrays 52, the outer antenna arrays 54, and the primary bus structure 22. Figure 20 illustrates another embodiment 130 for the Earth-facing antenna array 12. The pattern shown in Figure 20 utilizes uplink antennas 18a and downlink antennas 18b that reside on the inner antenna arrays 52, the outer antenna arrays 54, and the primary bus structure 22. Figures 19 and 20 also present tables which identify the various antenna patterns shown on the Earth-facing array 12. Each pattern is identified as transmit or receive, and the number of elements, gain and number of arrays are also specified.

CONCLUSION

Although the present invention has been described in detail with reference to particular preferred and alternative embodiments, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow.

INDUSTRIAL APPLICABILITY

The *Modular Communication Satellite* described above will help to overcome the limits that circumscribe the performance and potential of existing telephone systems. The present invention is capable of offering continuous voice, data and video service to customers across the globe on the land, on the sea, or in the air. Instead of merely improving upon or expanding existing land-based systems, the present invention bypasses centralized terrestrial switching hardware by placing all the intelligence of the network in orbit. Unlike conventional hierarchical systems, which are linked together by a complex web of wires, cables, glass fibers, and microwave repeaters that are very expensive to build and maintain, the present invention liberates the true communications potential of existing land-based networks by routing signals through spacecraft in low Earth orbit. The present invention will revolutionize the telecommunications industry, and offer a wide spectrum of services and industrial opportunities around the world.

LIST OF REFERENCE CHARACTERS

10	Satellite
12	Earth-facing antenna array
14	30 GHz uplinks
16	20 GHz downlinks
18	Antennas
18a	Uplink antennas
18b	Downlink antennas
20	M/FTSL antenna panel set
22	Primary bus structure
24	Antenna facet panels
26	ISL antenna array
28	Individual ISL antenna
30	60 GHz intersatellite links
32	Astromast™ boom
34	Boom crossmast
36	Solar array storage boom

- 38 Amorphous silicon solar array
- 40 Inflatable boom
- 42 Cantilever boom
- 44 Pulse plasma thrusters
- 46 Storage batteries
- 48 Shunt regulators
- 50 Perspective view of assembled satellite
- 52 Inner antenna array
- 52a First inner antenna array
- 52b Second inner antenna array
- 52c Third inner antenna array
- 52d Fourth inner antenna array
- 54 Outer antenna array
- 54a First outer antenna array
- 54b Second outer antenna array
- 54c Third outer antenna array
- 54d Fourth outer antenna array
- 56 Component storage compartment
- 58 Solar array attachment structure
- 60 Command and data handling subsystem
- 62 Attitude/orbit determination and control subsystem
- 64 Communications payload subsystem
- 66 Front view of assembled satellite
- 68 Side view of assembled satellite
- 70 Front view of satellite before launch
- 74 Top cut-away view of satellite in launch vehicle
- 80 Bottom cut-away view of satellite within launch vehicle
- 82 Illustration of satellite deployed in low Earth orbit
- 84 Illustration of deployed satellite with detached solar array storage booms
- 86 Illustration of deployed satellite with extended Astromast™ boom
- 88 Depiction of expanding solar array boom and extension of outer antenna arrays
- 90 Antenna deployment hinges
- 92 Inner antenna panel on outer array
- 94 Central antenna panel on outer array
- 96 Outer antenna panel on outer array
- 98 Boom hinge mechanism
- 100 Depiction of extended solar array boom and extension of inner antenna arrays

102	Inside antenna panel on inner array
104	Middle antenna panel on inner array
106	Outside antenna panel on inner array
108	Deployment mechanism
110	Depiction of inflating solar arrays
112	Photovoltaic cells
114	Film substrate
116	Photocurable chemical vapor
118	Inflation gas
120	Fully deployed solar array
122	Side view of fully deployed satellite
124	Front view of fully deployed satellite
126	Illustration of fully deployed earth-facing antenna arrays
128	Alternate embodiment of earth facing antenna arrays
130	Another embodiment of earth facing antenna arrays
E	Earth
F	Fixed terminal
G	Gateway
LV	Launch vehicle
LVI	Launch vehicle interior
M	Mobile terminal
P	Portable terminal
PDE	Payload dynamic envelope
PN	Person
S	Sun

CLAIMS

What is claimed is:

1. A spacecraft apparatus (10) comprising at least one foldable antenna array (12) and a foldable solar power array (38) therefor, characterized in that means (32) are provided for moving the solar power array relative to the or each antenna array whereby, when the arrays are unfolded, the solar power array may be relatively moved to provide shielding for the antenna array from solar radiation.
2. A spacecraft apparatus according the Claim 1, wherein the antenna array (12) and the solar power array (38) are interconnected by means of a boom element (32) which is longitudinally extendable and which is connected to at least one of the arrays (12, 38) via a rotary coupling.
3. A spacecraft apparatus according the Claim 1 or 2, wherein the solar power array (38) is mounted on a plurality of boom members (36, 40, 42), one or more of which (40) are inflatable by means of deployment means (108).
4. A spacecraft apparatus according to Claim 3, wherein means (108, 116) are provided for rendering the inflatable boom members (40) rigid after inflation.
5. A spacecraft apparatus according to Claim 4, wherein the rigidity-producing means (108, 116) comprise means for supplying a photocurable vapor (116) to the inflatable boom members (40).
6. A spacecraft apparatus according to any of Claims 3 to 5, wherein one or more of said boom members (36) is a storage boom member which, before unfolding, stores at least part of the solar power array (38) and/or one or more of the inflatable boom members (40).
7. A spacecraft apparatus according to Claim 6, wherein the or each storage boom member (36), before unfolding, is attached to the remainder of the spacecraft apparatus by means of an attachment structure (58), detachment means being provided to disconnect the storage boom member(s) from the attachment structure.
8. A spacecraft apparatus according to any preceding claim, and further comprising an attitude/orbit determination and control subsystem (62) which activates thrusting means (44) for guiding the spacecraft apparatus after launch thereof.

9. A spacecraft apparatus according to any of Claims 2 to 5, and to Claim 6, wherein said attitude/orbit determination and control subsystem (62) controls the deployment of the boom element (32) and/or boom member(s) (32; 36, 40, 42).

10. A spacecraft apparatus (10) according to any preceding claim and comprising a central structure (22) with foldable antenna array sets (52, 54) arranged around its periphery, the members of a first array set (54) being arranged alternately with the members of the second array set (52), the members of the first array set (54) when folded, being located at an offset distance from a major surface of the central structure (22), and the members of the second array set (52), when folded, being located relatively close to said major surface and within said offset distance, whereby after unfolding of the first array set (54), the second array (52) set may be unfolded.

11. A method of deploying a spacecraft apparatus (10) according to Claim 1, comprising launching the apparatus with the antenna and solar power arrays (12, 38) in folded configuration, and then moving the arrays relatively apart, unfolding them, and relatively rotating them so that the solar power array (38) provides shielding for the antenna array (12) from solar radiation.

12. A method of deploying a spacecraft apparatus (10) according to Claim 11, wherein the solar power array (38) is mounted on a plurality of boom members (36, 40, 42) one or more of which (40) are inflatable, the method comprising the further step of inflating the inflatable boom member(s) (40).

13. A method of deploying a spacecraft apparatus (10) according to Claim 12, wherein the method comprises the further step of supplying a photocurable vapor (116) to the inflatable boom member(s) (40) whereby to impart rigidity thereto after inflation.

14. A satellite apparatus (10) capable of being placed in a low Earth orbit using a launch vehicle (LV) for providing communications among a plurality of portable (P), mobile (M), and fixed (F) terminals and gateways (G) and among other of said satellite apparatus comprising:

an Earth-facing antenna array (12);

said Earth-facing antenna array (12) including a plurality of substantially polygonal, planar antenna panels (92, 94, 96, 102, 104, & 106);

said plurality of substantially polygonal, planar antenna panels (92, 94, 96, 102, 104, & 106) being maintained in an orbital orientation which aims said plurality of substantially polygonal, planar antenna panels (92, 94, 96, 102, 104, & 106) generally towards the Earth;

a plurality of hinge elements (90); said plurality of hinge elements (90) being used to mechanically couple said plurality of substantially polygonal, planar antenna panels (92, 94, 96, 102, 104, & 106);

5 said antenna array (12) being capable of being stowed in a coaxially nested arrangement with other of said antenna arrays (12) for transportation in said launch vehicle (LV);

a space-facing array (26);

said space-facing array (26) including a plurality of intersatellite antennas (28); each of said plurality of intersatellite antennas (28) plurality of being maintained in an orbital orientation which aims said intersatellite antennas (28) generally tangential to surface of the Earth;

10 a solar array (38) for supplying power to said Earth-facing antenna array (12);

said solar array (38) being capable of being stored substantially near said Earth-facing antenna array (12);

said solar array (38) being capable of being deployed away from said Earth-facing antenna array (12) and unfurled to a fully extended position (120);

15 said solar array (38) including a layer of photovoltaic cells (112);

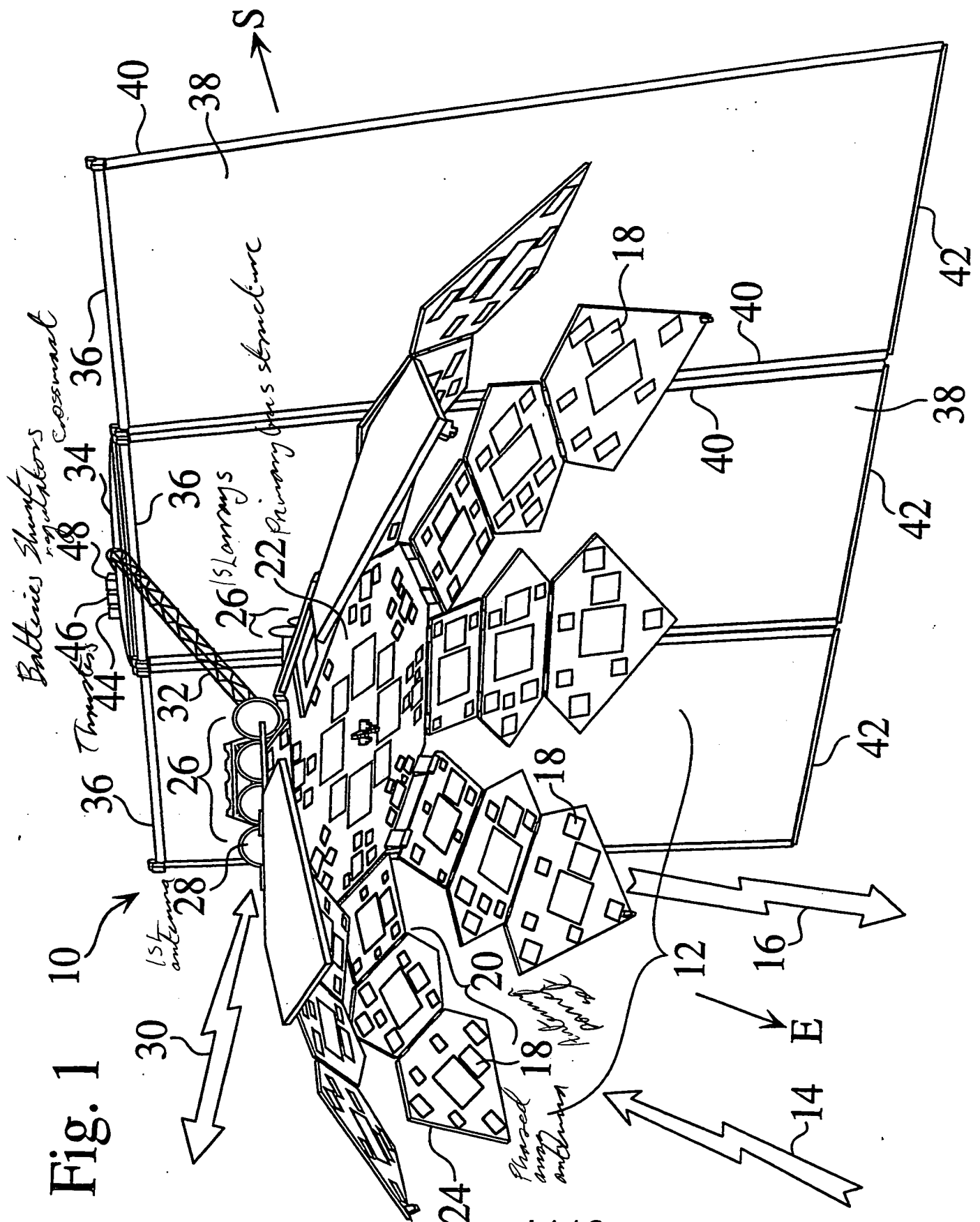
said solar array (38) being mechanically connected to said Earth-facing antenna array (12);

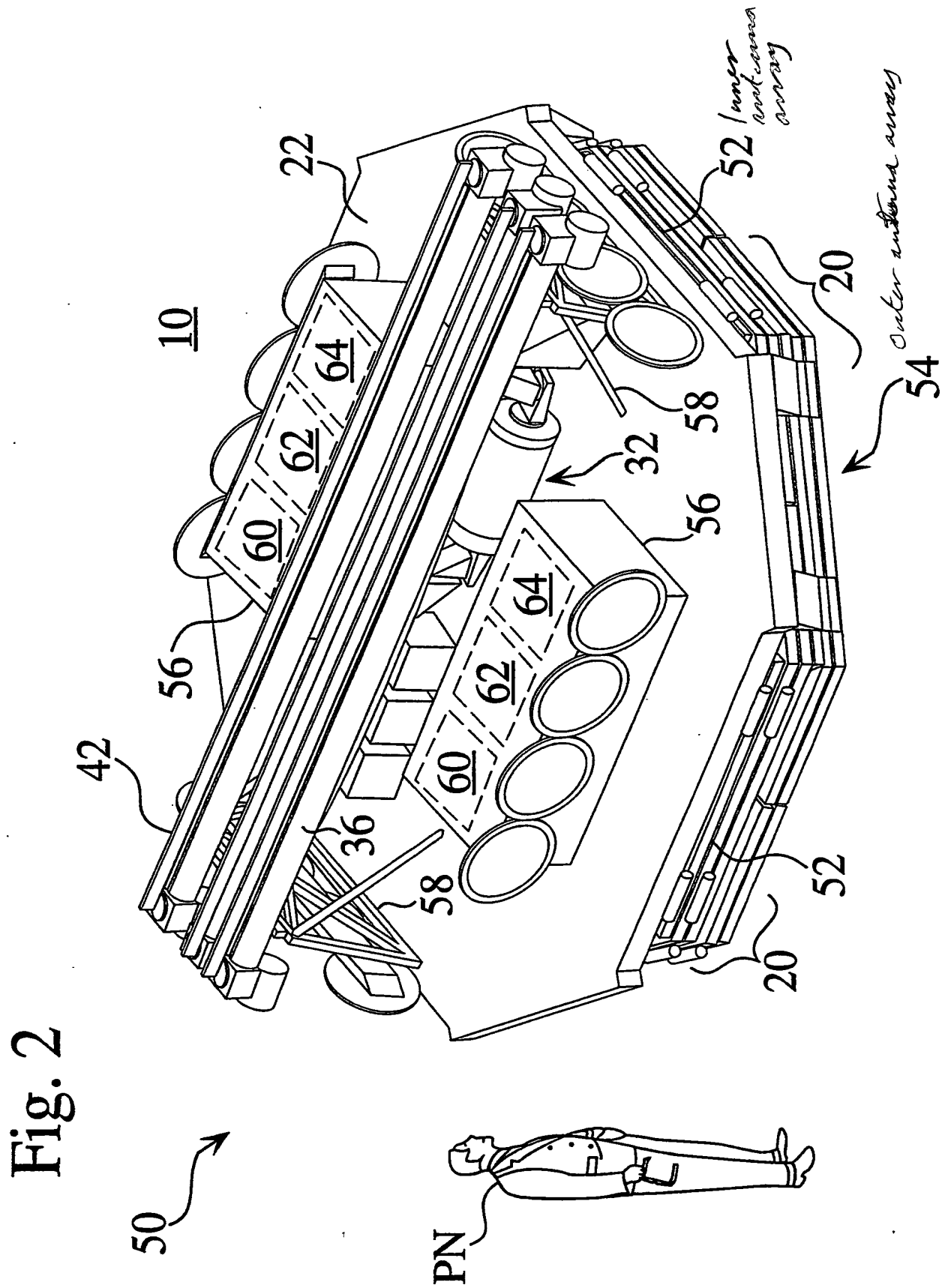
said solar array (38) being capable of being rotated to optimize the collection of solar radiation; and

20 said solar array (38) being capable of being positioned to provide shielding of solar radiation for said Earth-facing antenna array (12).

15. A spacecraft apparatus (10) comprising an array (38) mounted on a plurality of boom members (36, 40, 42) characterized in that one or more of the boom members (40) are inflatable, and in that means (108, 116) are provided for rendering the inflatable boom members (40) rigid after inflation.

16. A method of deploying a spacecraft apparatus (10) comprising an array (38) mounted on a plurality of boom members (36, 40, 42) one or more of which (40) are inflatable, the method comprising the steps of inflating the inflatable boom members (40) and then producing rigidity in the inflated members.





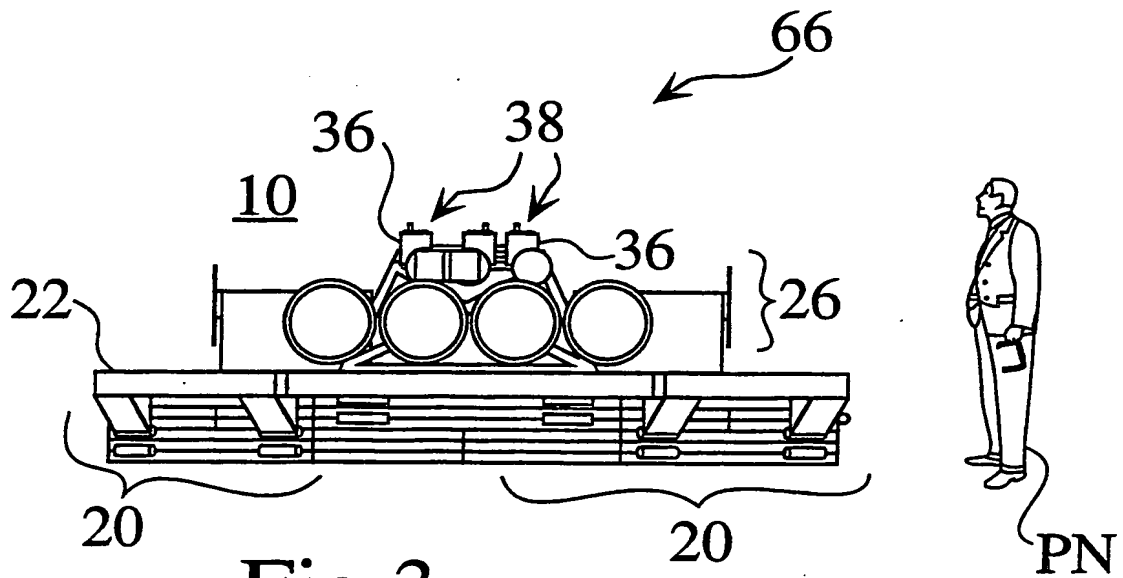


Fig.3

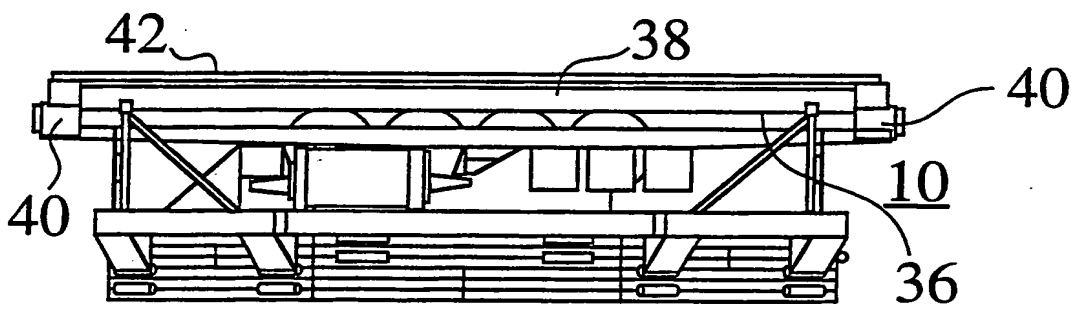


Fig.4

Fig.6

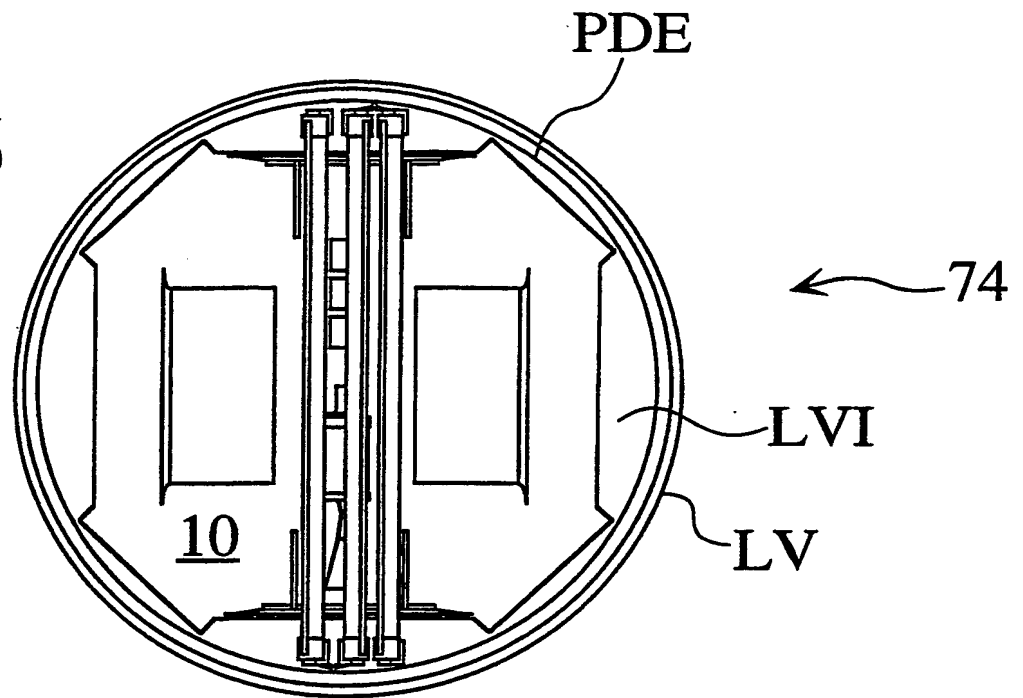


Fig.5

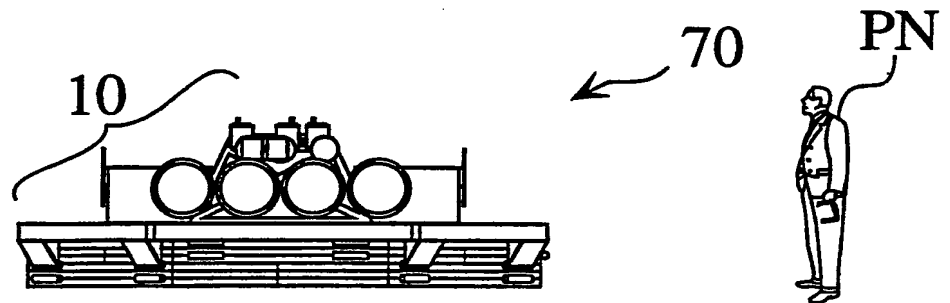
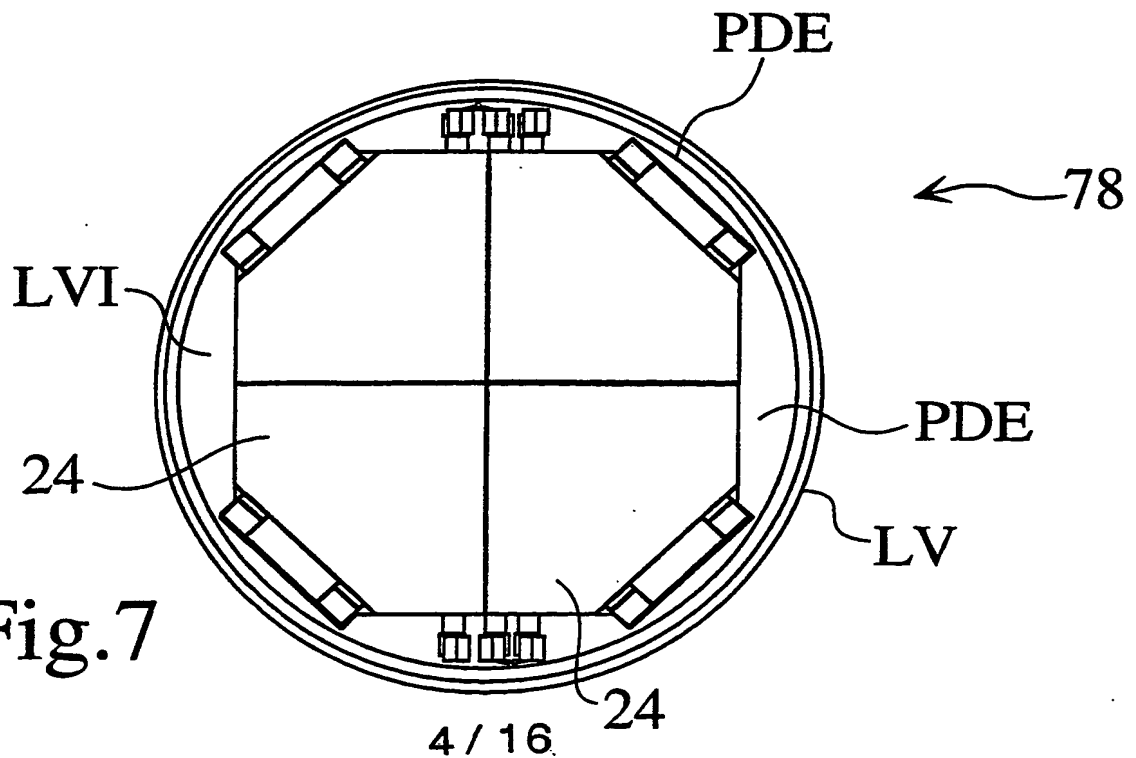


Fig.7



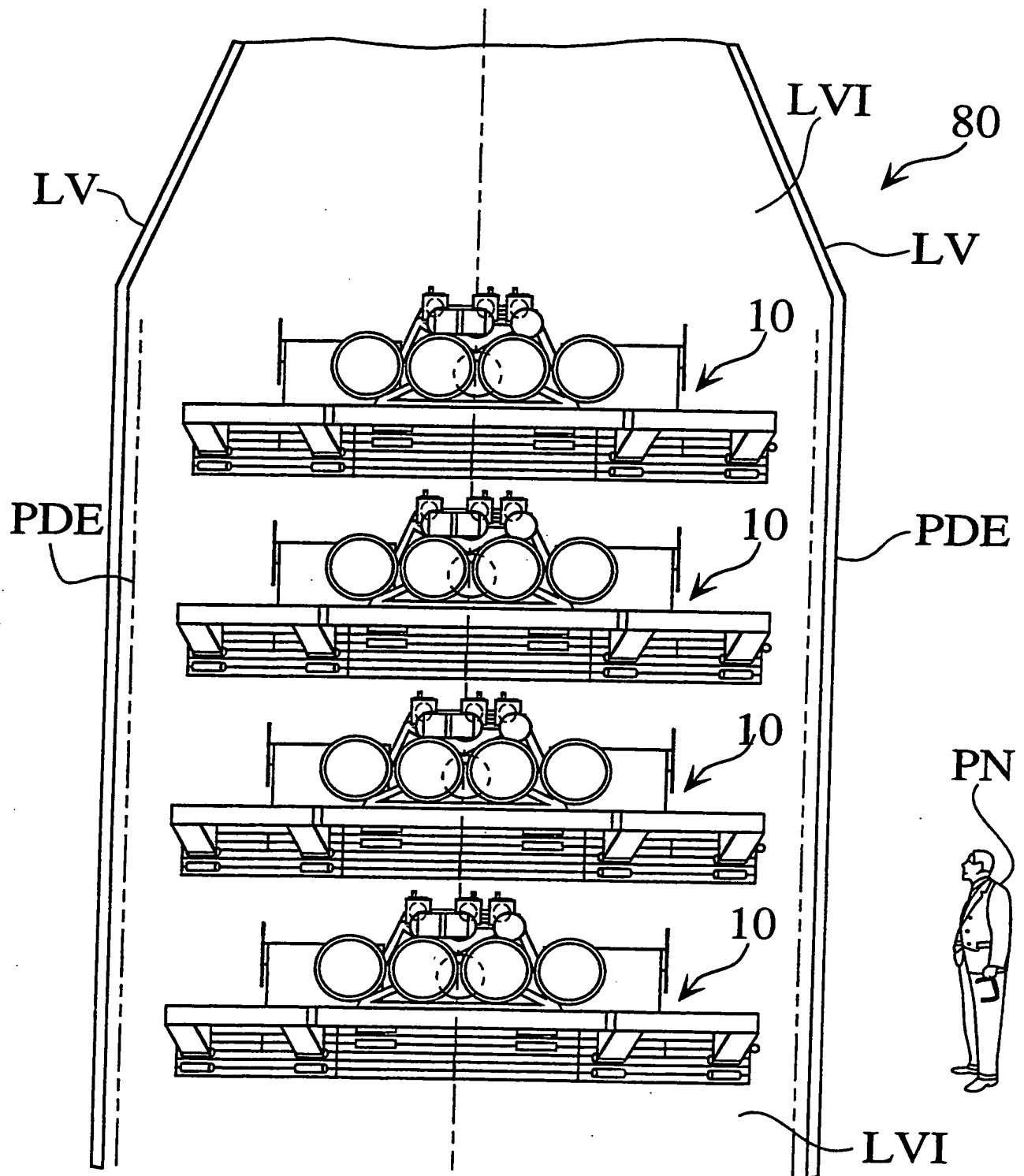
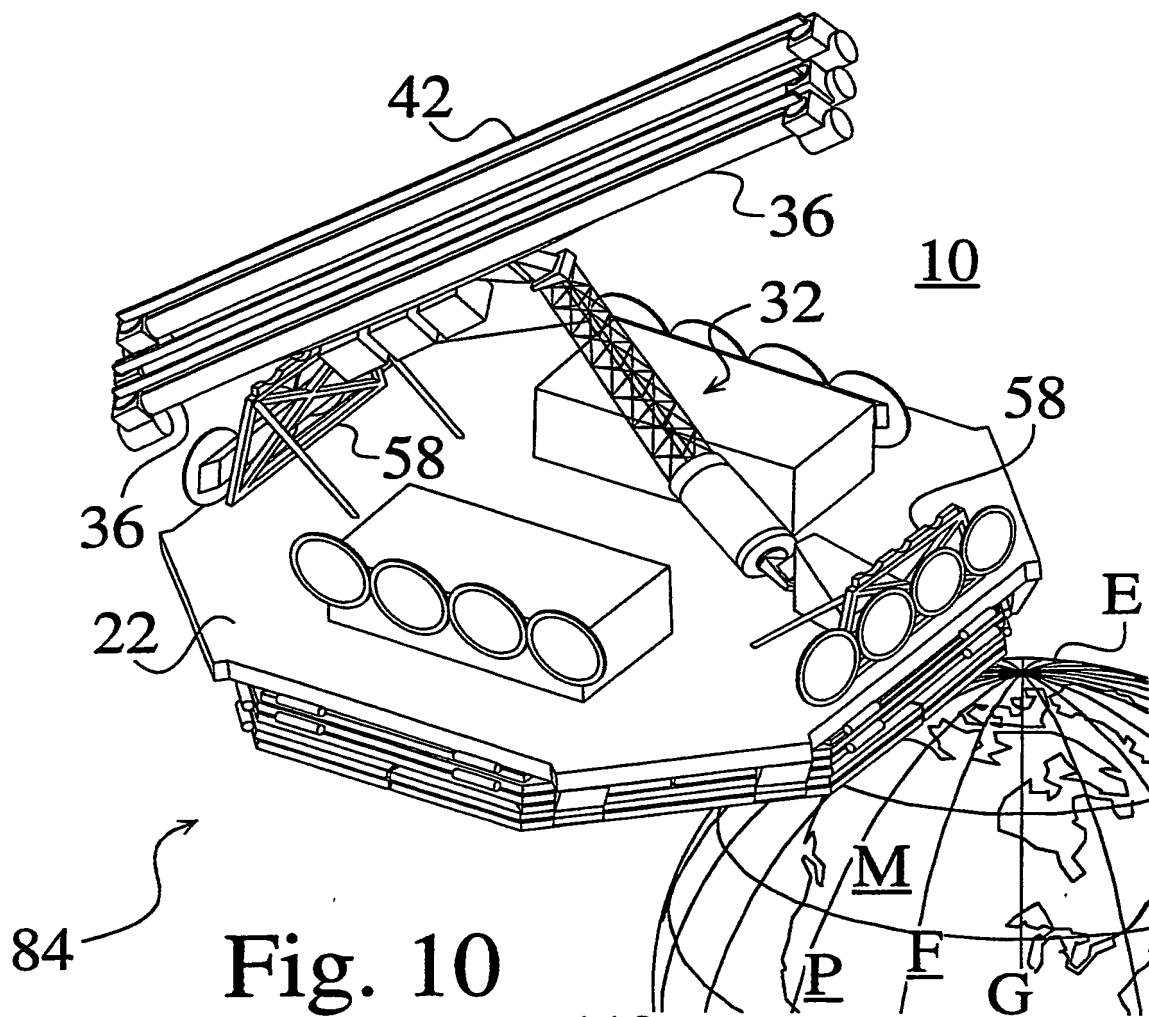
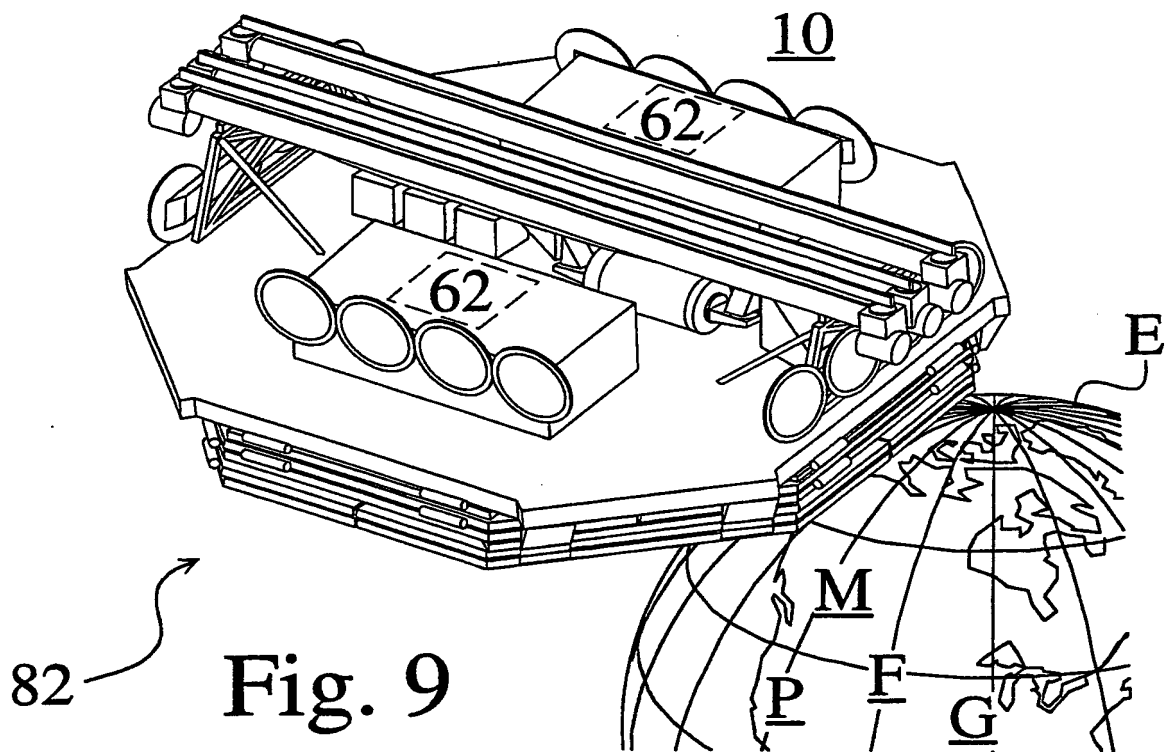
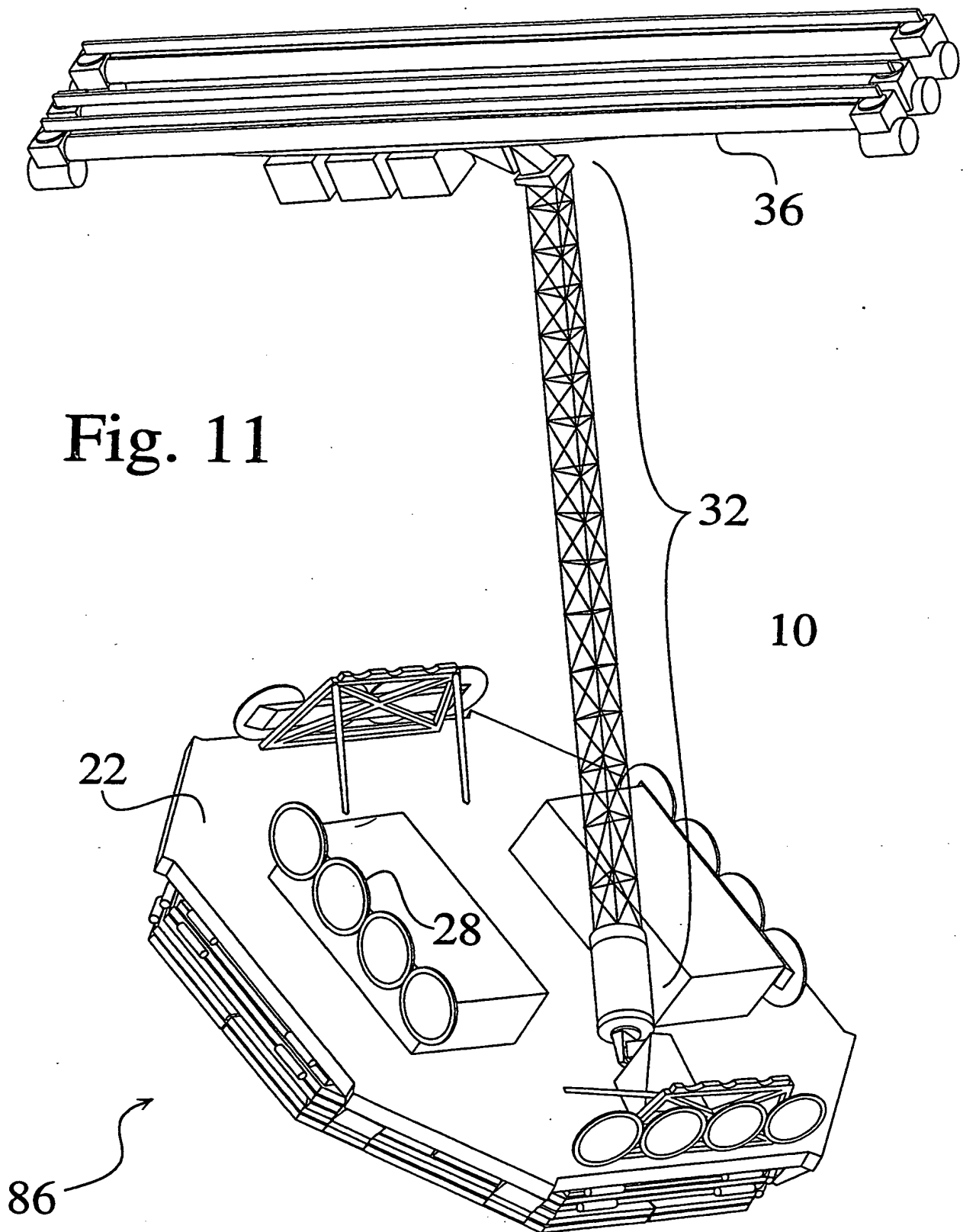
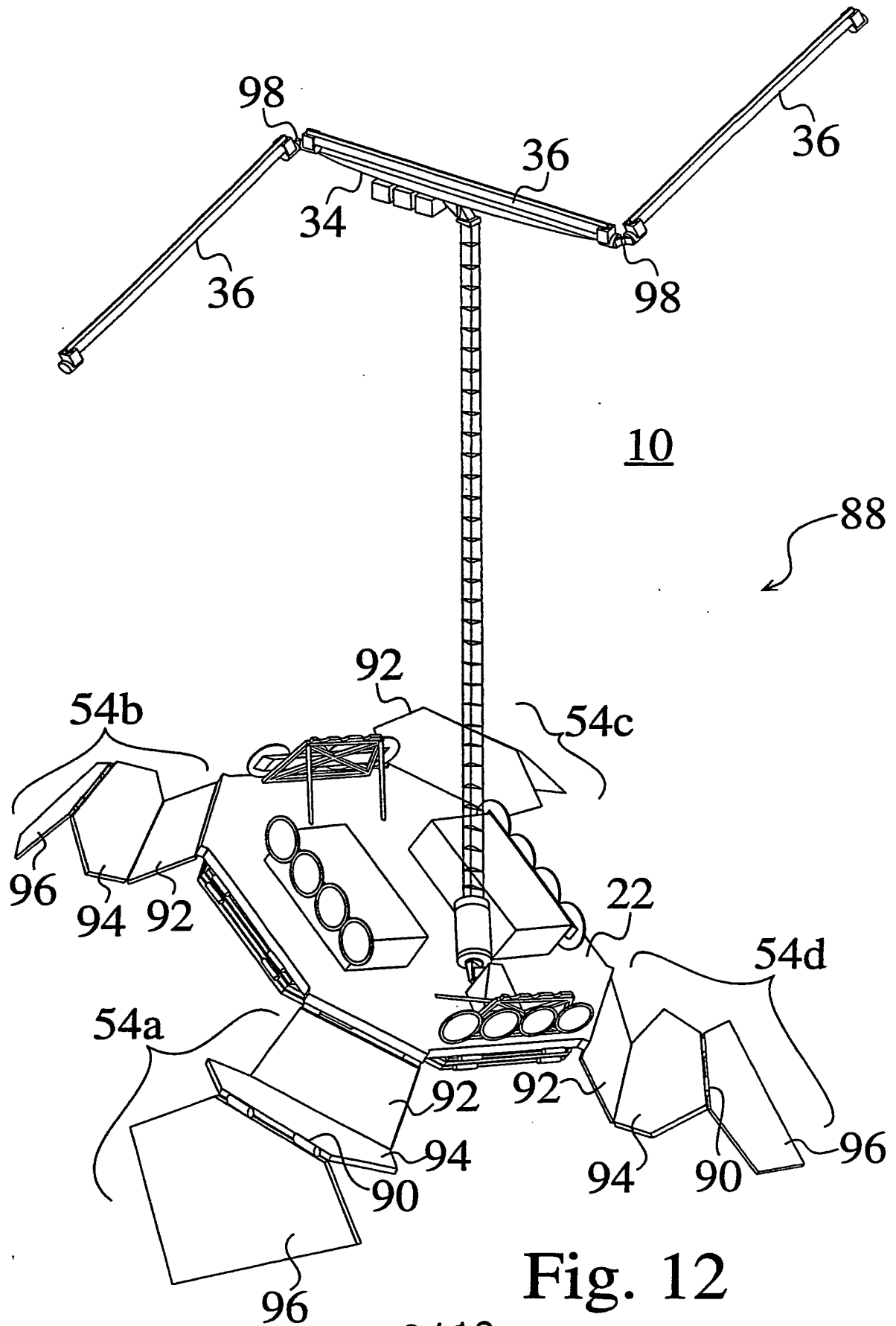
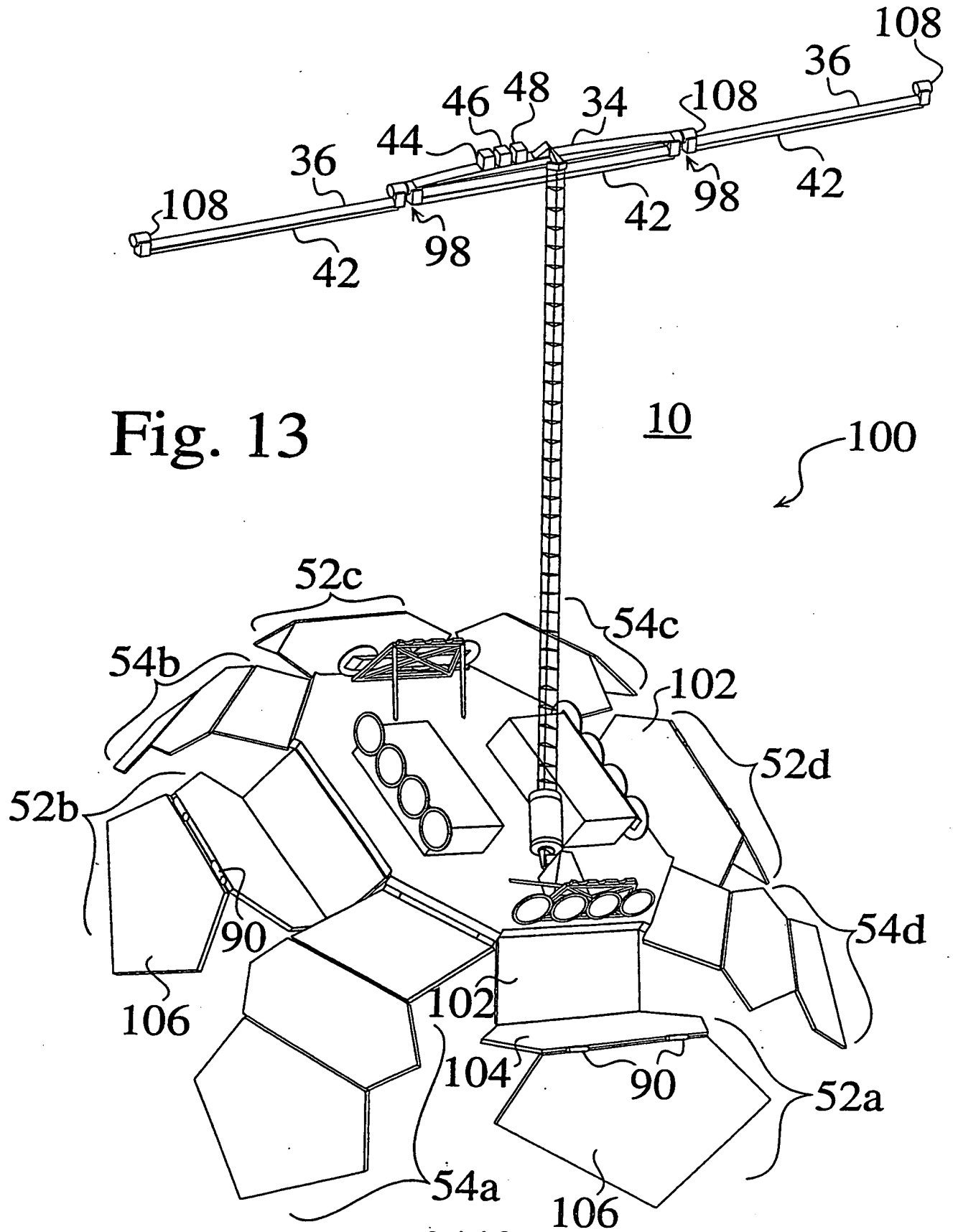


Fig.8









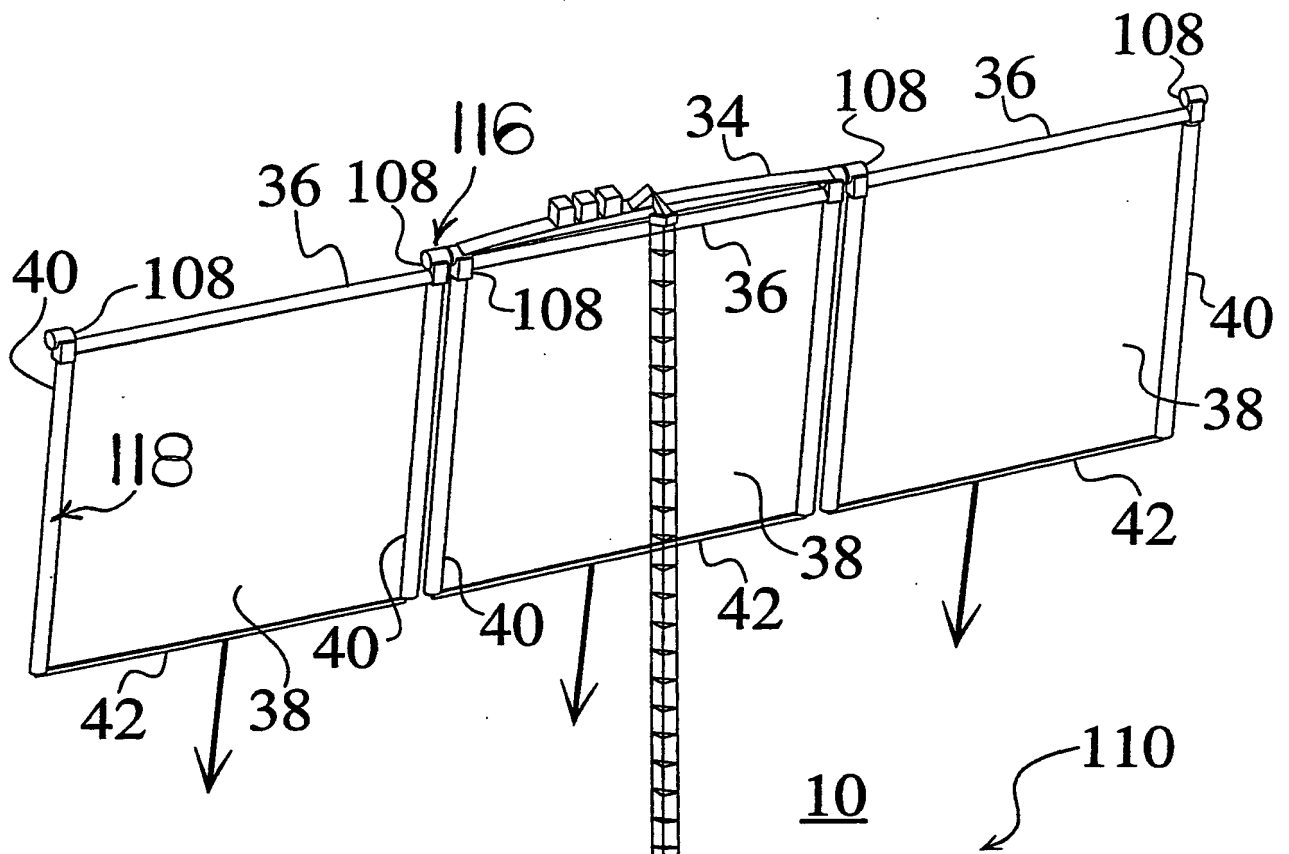
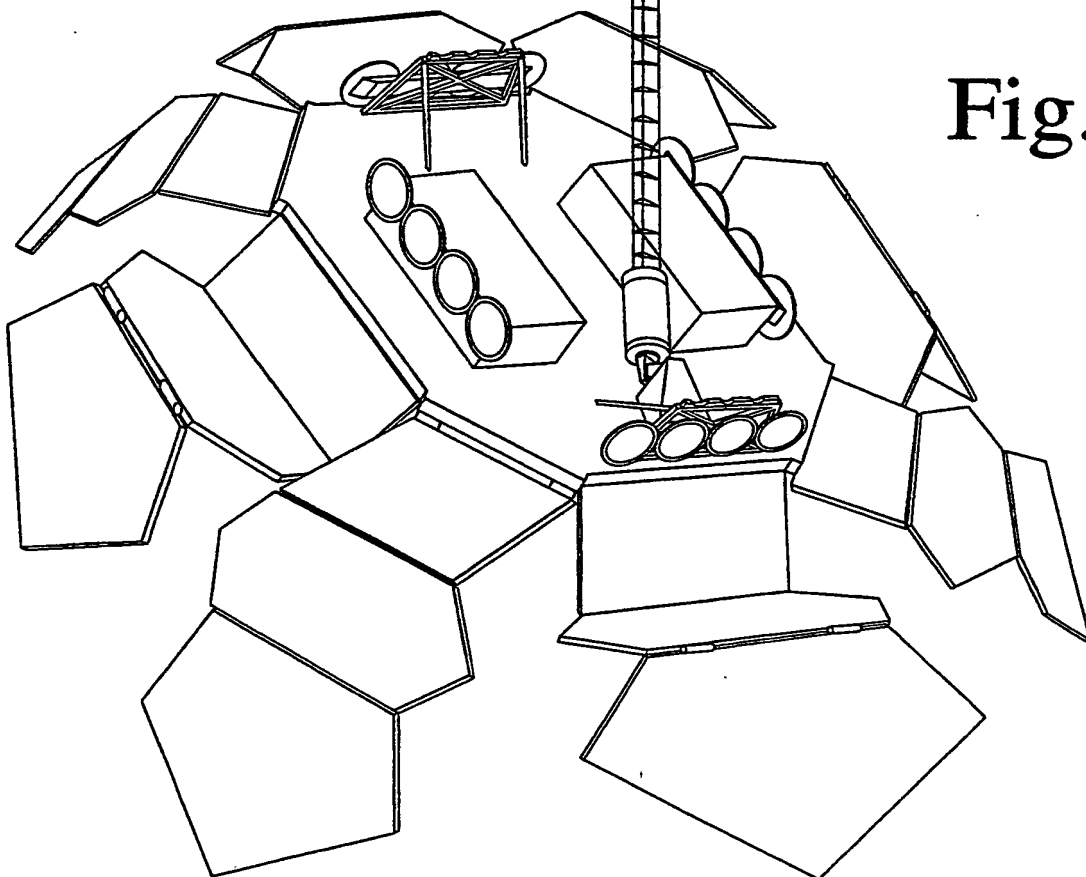
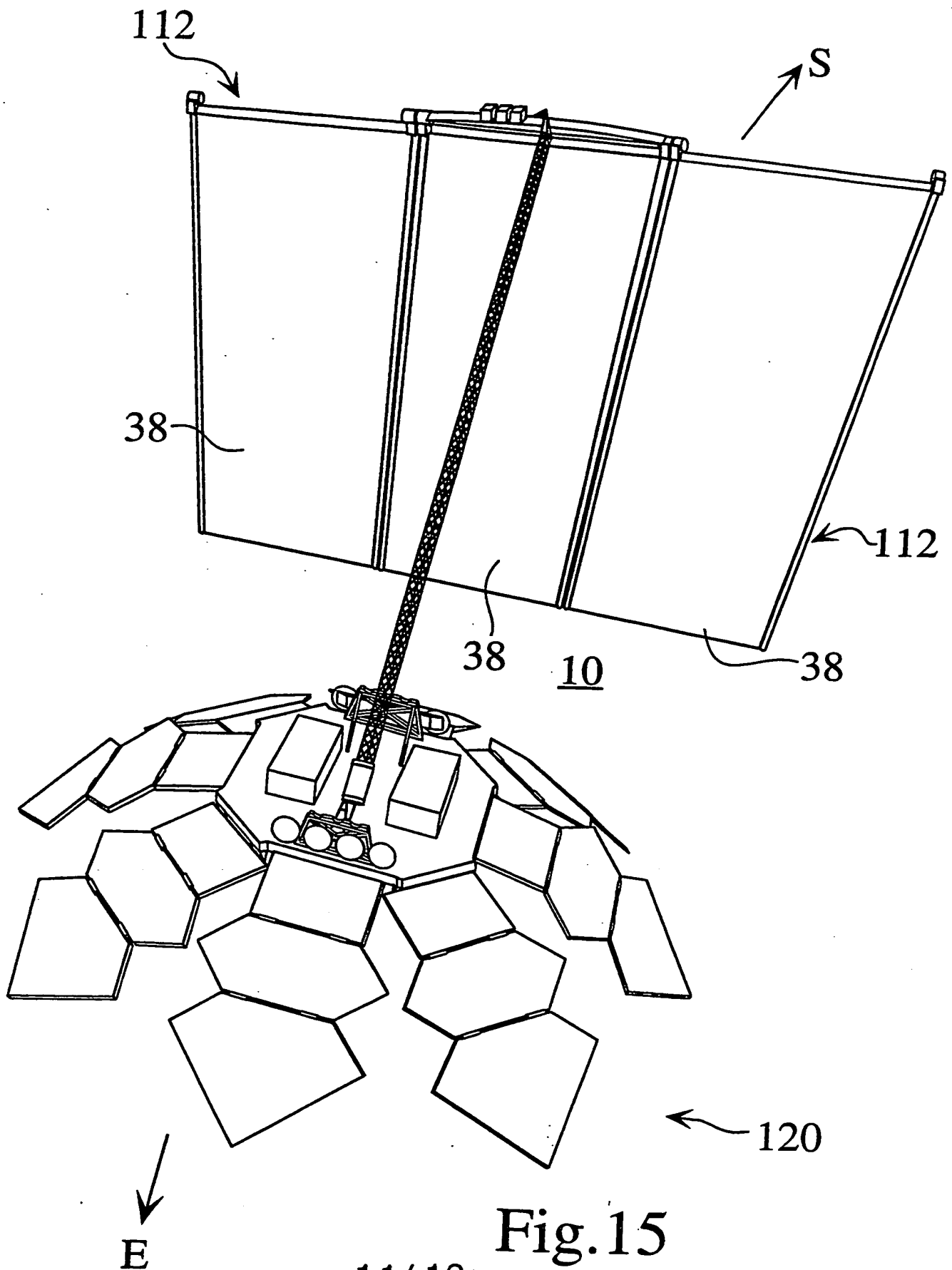
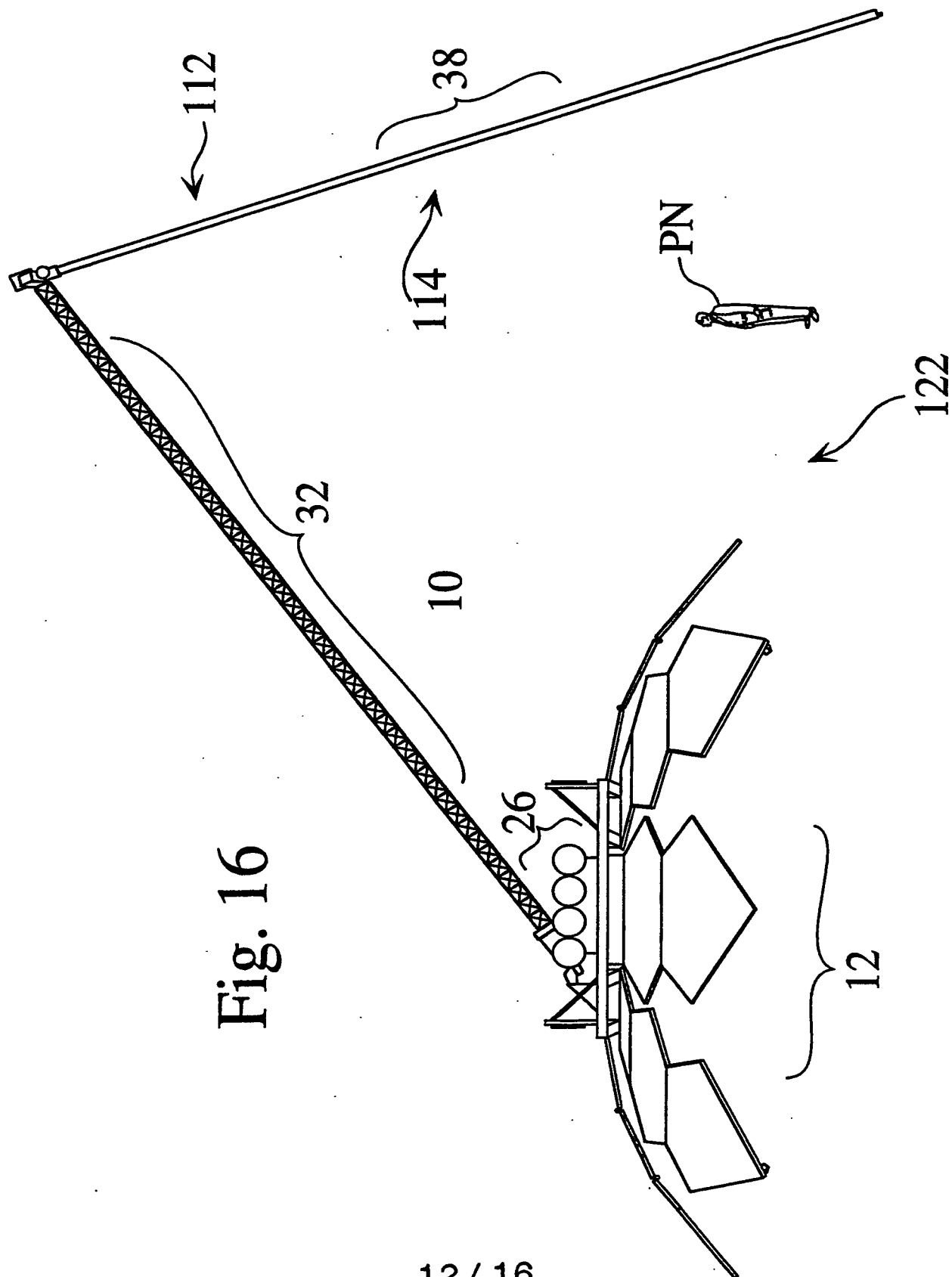
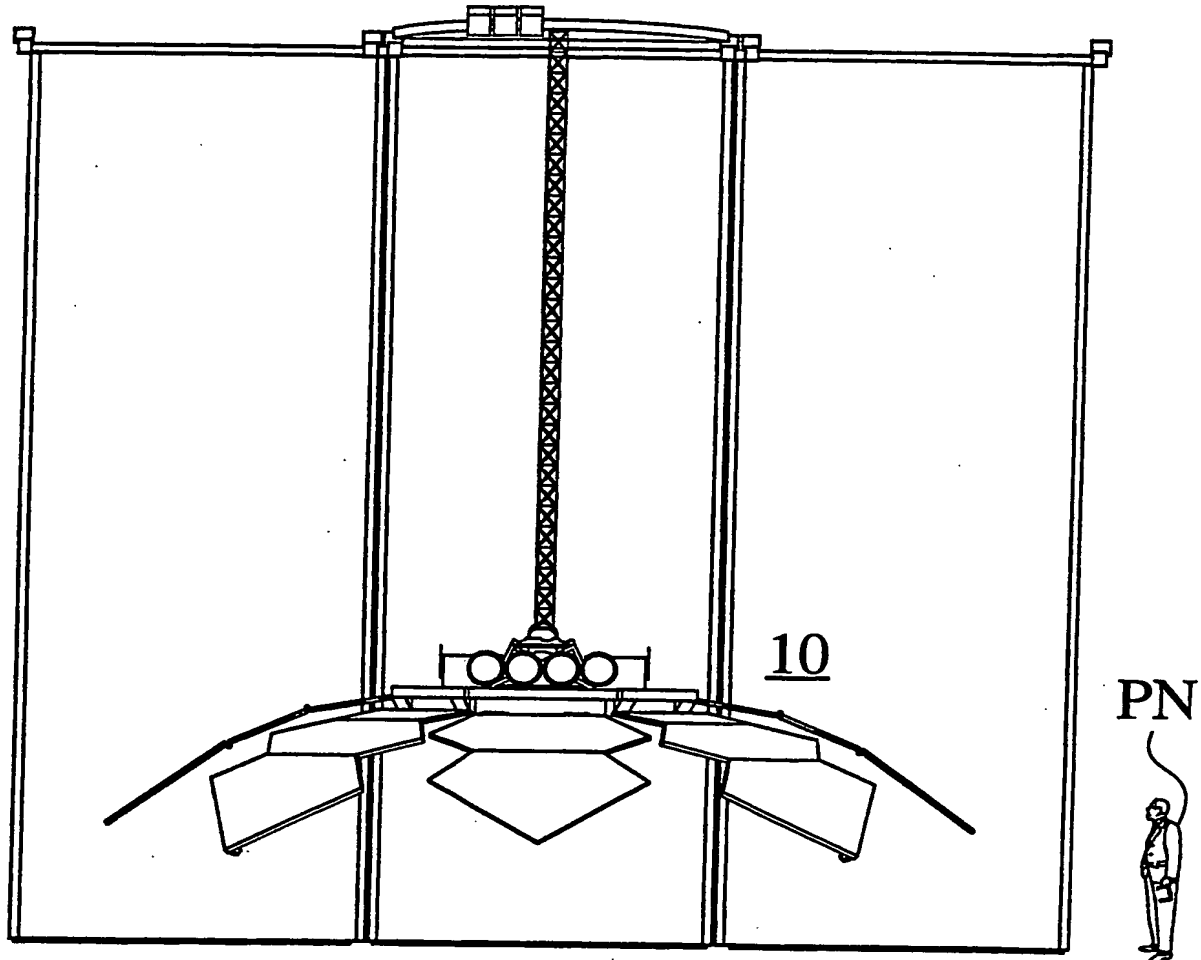


Fig. 14









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Fig. 17

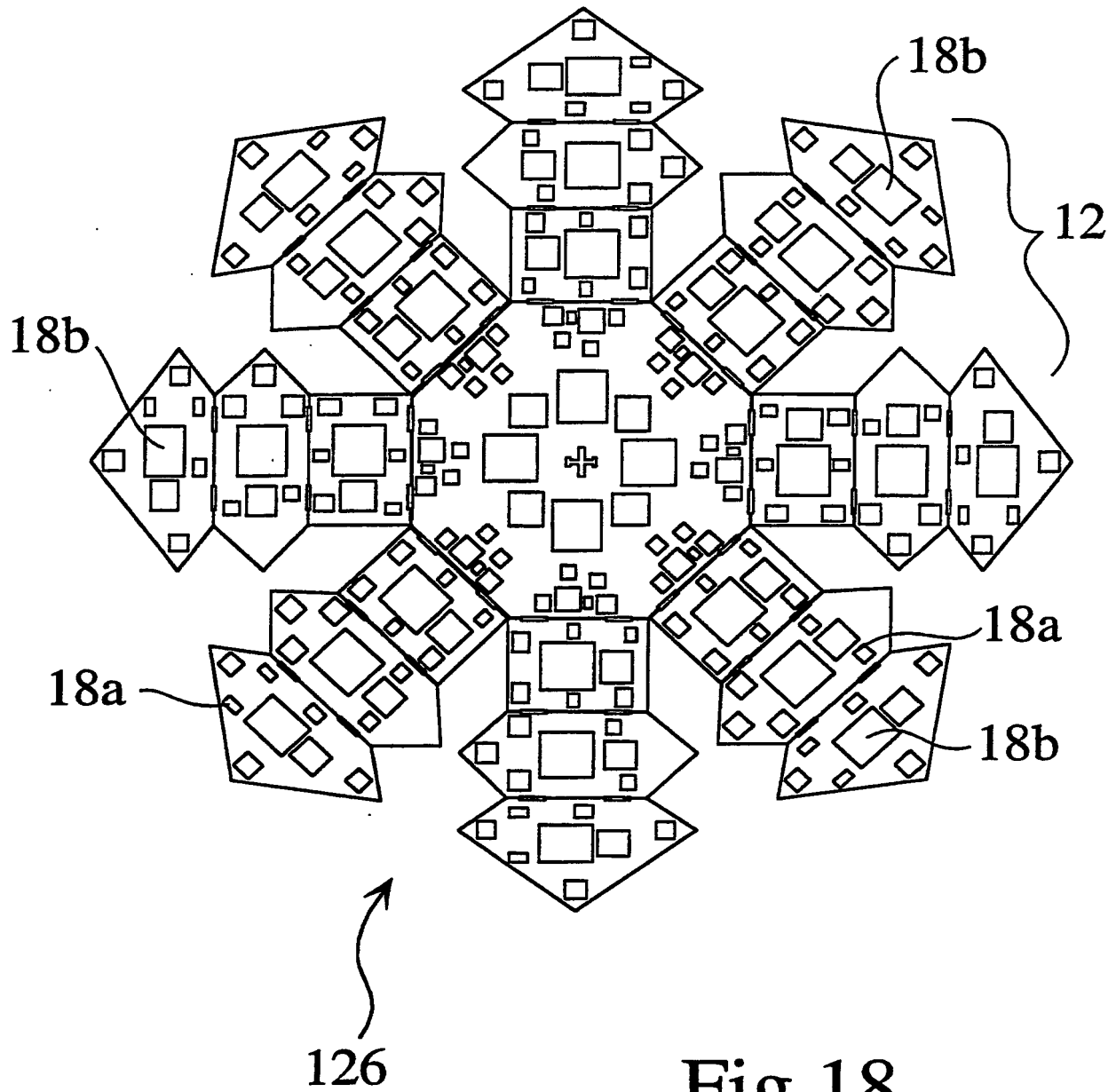
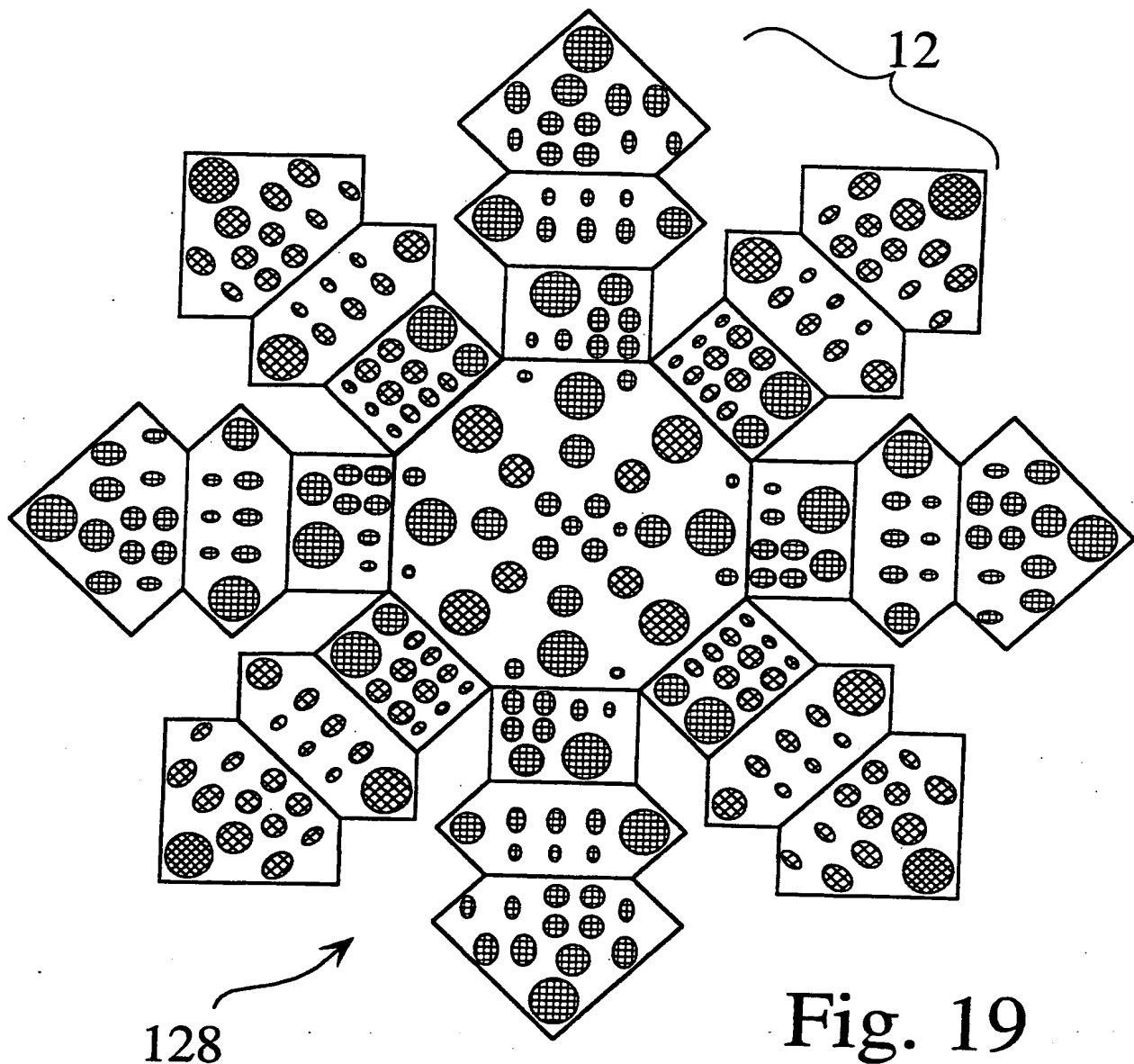


Fig.18



TRANSMIT RECEIVE #ELEMENTS GAIN (dB) #ARRAYS

⊕	⊙	316	31.7	10
⊕	⊙	320	31.7	32
⊕	⊙	484	33.4	48
⊕	⊙	684	35.0	48
⊕	⊕	2128	41.0	64
	⊕	1020	38.0	68

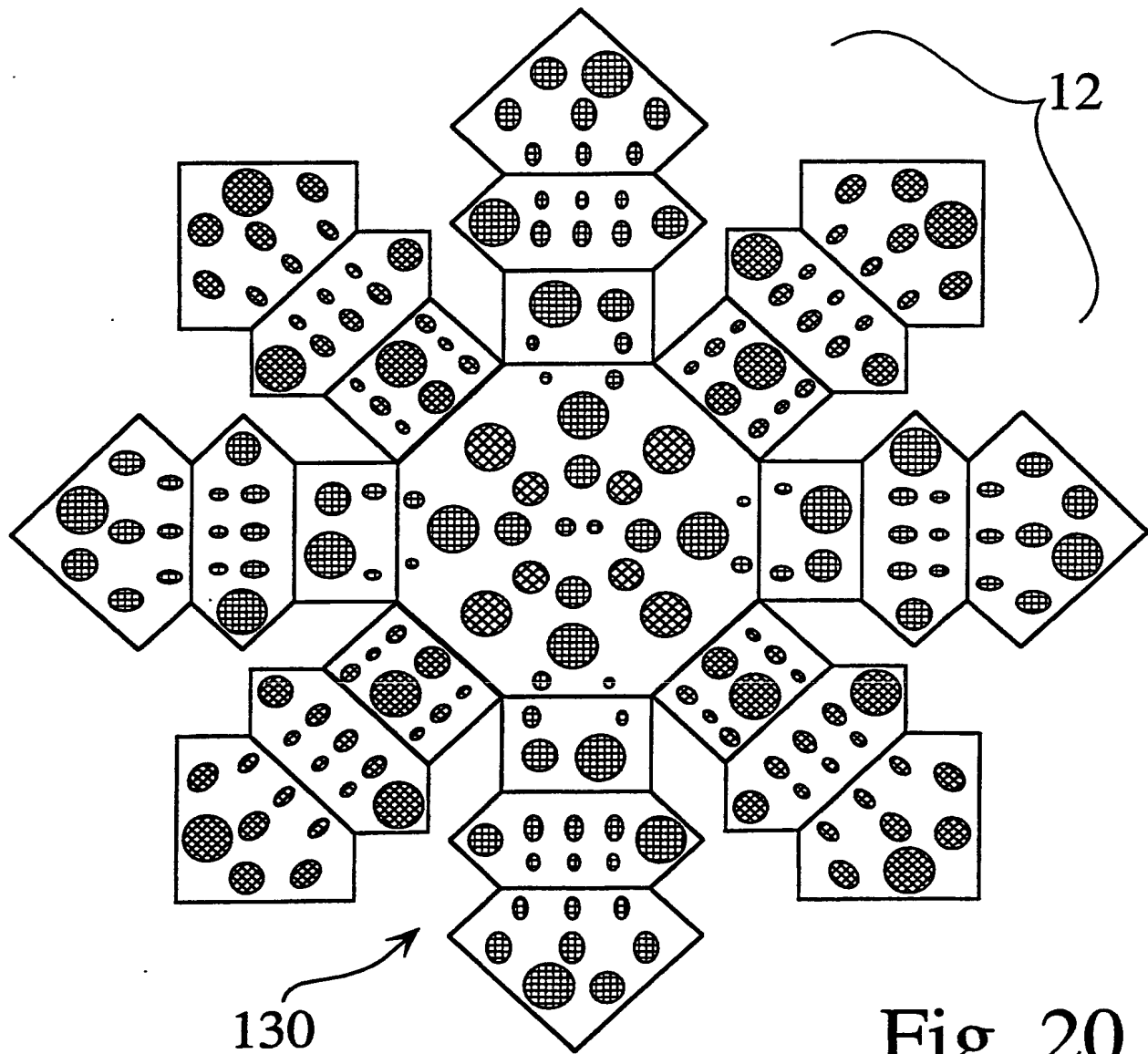


Fig. 20

TRANSMIT	RECEIVE	# ELEMENTS	GAIN (dB)	# ARRAYS
⊕	⊙	316	31.7	10
⊕	⊙	320	31.7	32
⊕	⊙	484	33.4	48
⊕	⊙	684	35.0	48
⊕	⊙	2128	41.0	64

⊕	⊙	316	31.7	10
⊕	⊙	320	31.7	32
⊕	⊙	484	33.4	48
⊕	⊙	684	35.0	48
⊕	⊙	2128	41.0	64

A. CLASSIFICATION OF SUBJECT MATTER

IPC 5 H01Q1/28 H01Q1/08 B64G1/44 B64G1/58

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 H01Q B64G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO,A,94 02972 (CALLING COMMUNICATIONS) 3 February 1994 see page 11, line 11 - line 16; figure 27 ---	1,11,14
A	EP,A,0 260 442 (ERNO RAUMFAHRTTECHNIK) 23 March 1988 see claims 1,2; figures 1,2 ---	1,11
A	EP,A,0 134 288 (ERNO RAUMFAHRTTECHNIK) 20 March 1985 see abstract see claims 1,2,5,9; figures 1-3 ---	1,11
A	WO,A,93 09578 (CALLING COMMUNICATIONS) 13 May 1993 see page 4, line 2 - line 19; figures 1,2 --- -/--	14

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Date of the actual completion of the international search

10 October 1994

Date of mailing of the international search report

21.10.94

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A	<p>PROCEEDINGS OF THE 1991 IEEE NATIONAL RADAR CONFERENCE, March 1991, LOS ANGELES, CALIFORNIA pages 41 - 45 HIGHTOWER ET AL. 'A SPACE-FED PHASED ARRAY FOR SURVEILLANCE FROM SPACE' see page 42; figure 2 -----</p>	14

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		JP-A- 63082900	13-04-88
EP-A-0134288	20-03-85	JP-A- 60056700	02-04-85
		US-A- 5014936	14-05-91
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		EP-A- 0611491	24-08-94

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